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Abstract

Nowadays, smart devices which can be controlled remotely by the Internet appear in the preference setting rather than the manual control to improve the standard of living. In this paper, a domotic system integrated into PV power generation has been developed on the Internet of Things (IoT). The system uses sensors for fire detection and monitoring of the temperature and relative air humidity. Based on real-time, the home automation off-grid system is developed so that makes the system cost-effective and portable.

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Abstract

Nowadays, smart devices which can be controlled remotely by the Internet appear in the preference setting rather than the manual control to improve the standard of living. In this paper, a domotic system integrated into PV power generation has been developed on the Internet of Things (IoT). The system uses sensors for fire detection and monitoring of the temperature and relative air humidity. Based on real-time, the home automation off-grid system is developed so that makes the system cost-effective and portable.

Keywords: Control Platform; Domotic System; Internet of Things; Smart off-Grid.

1. Introduction

The resources interconnected to a home automation system and powered by photovoltaic panels have become a great ally to the use of alternative energies [1-4]. Generally, the home automation and security system consist of three modules: the hardware interface module, webserver, and smart device. In this sense, the control of domotic systems based on IoT (Internet of Things) platforms is one of the most effective in availability. The IoT platform has as objective the integration of electronic equipment that uses internet-connected to a database, integrating the real world to a virtual world, facilitating the connectivity of people with things [5-6]. However, energy efficiency is hence one of the central issues that smart homes [7-9].

With the advent of smart inverters, energy monitors, and new generation battery storage, solar energy systems have joined the IoT, and they can become an essential piece of the puzzle of boosting energy efficiency in an automated, smart home [10]. This work aims to develop a prototype home automation system, using the concepts of home automation and the control of electrical loads responsible for triggering sensors.

2. Materials and Methods

In this work, the methodological development has been done in four stages, being: Correct sizing of the PV system, Install of Photovoltaic Generator, IoT acquisition and control platform, and home automation system.

2.1 Photovoltaic off-grid System

The development of this work is based entirely on the formulations of an off-grid generation with its autonomy (bank of batteries) [11]. A charge controller with PWM (Pulse Width Modulation) technology was used to manage battery charge, whose input voltage can vary from 12V to 24V and a maximum current of 20A. This power is regulated with enough levels to safely charge the battery, protecting the system from possible high loads and discharges, thus increasing battery life [12].

The inverters use materials with semiconductor characteristics with the function of static switches to carry out the switching responsible for DC-AC conversion. This conversion takes place through transformers, and the main characteristics of the output signal shape are generated through integrated circuits and control devices, which use PWM techniques [13]. Thus, the power will be following the standards for electrical equipment, which require AC voltage of substantially sinusoidal waveform with low harmonic distortion; usually, volts 127 V. Figure 1 illustrate the assembly of the photovoltaic system.

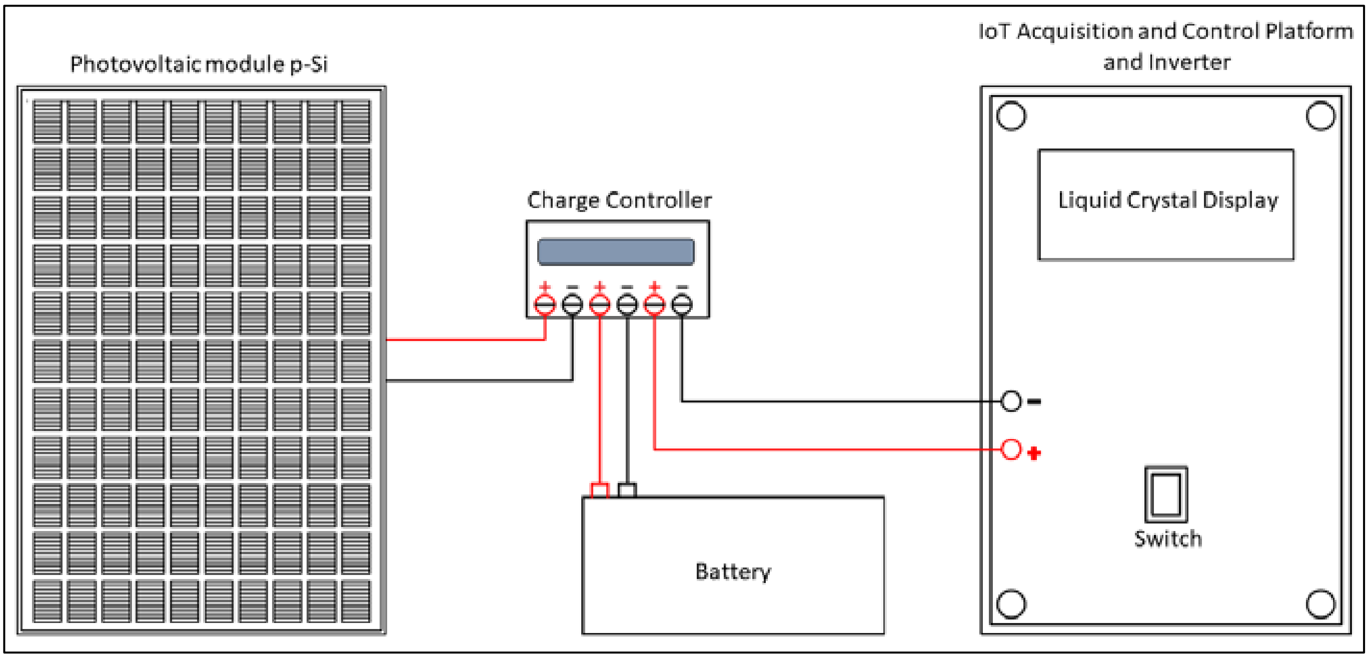

Figure 1. Single-line diagram of the photovoltaic system.

2.2 IoT Acquisition and Control Platform

The system proposed uses low-cost equipment, including the Arduino Mega microcontroller, which acts in the acquisition and control of an off-grid photovoltaic system. The objective is to integrate the generation and control data of the photovoltaic system into a home automation system. The acquisition and control platform is designed to monitor and control the photovoltaic system remotely. For the implementation of the platform, the Arduino programmable controller was used. This equipment controls the generation and distribution of isolated electrical power through sensors and actuators connected to its digital or analog ports. The Arduino uses the ATmega2560 microcontroller, and this model has 54 digital I/O (Input/Output) pins and 16 ADC (Analog Digital Converter) inputs, 4 UARTs (serial hardware ports), 16 MHz clock speed and rated voltage of 5V.

2.2.1 Hardware Architecture

The data acquisition of the photovoltaic system measured by sensors and connected in the Arduino are AC and DC, AC and DC voltage, the internal temperature of the inverter, and efficiency in the conversion of energy. These data help in decision making about the operation of the system. Figure 2 illustrates the proposed platform diagram.

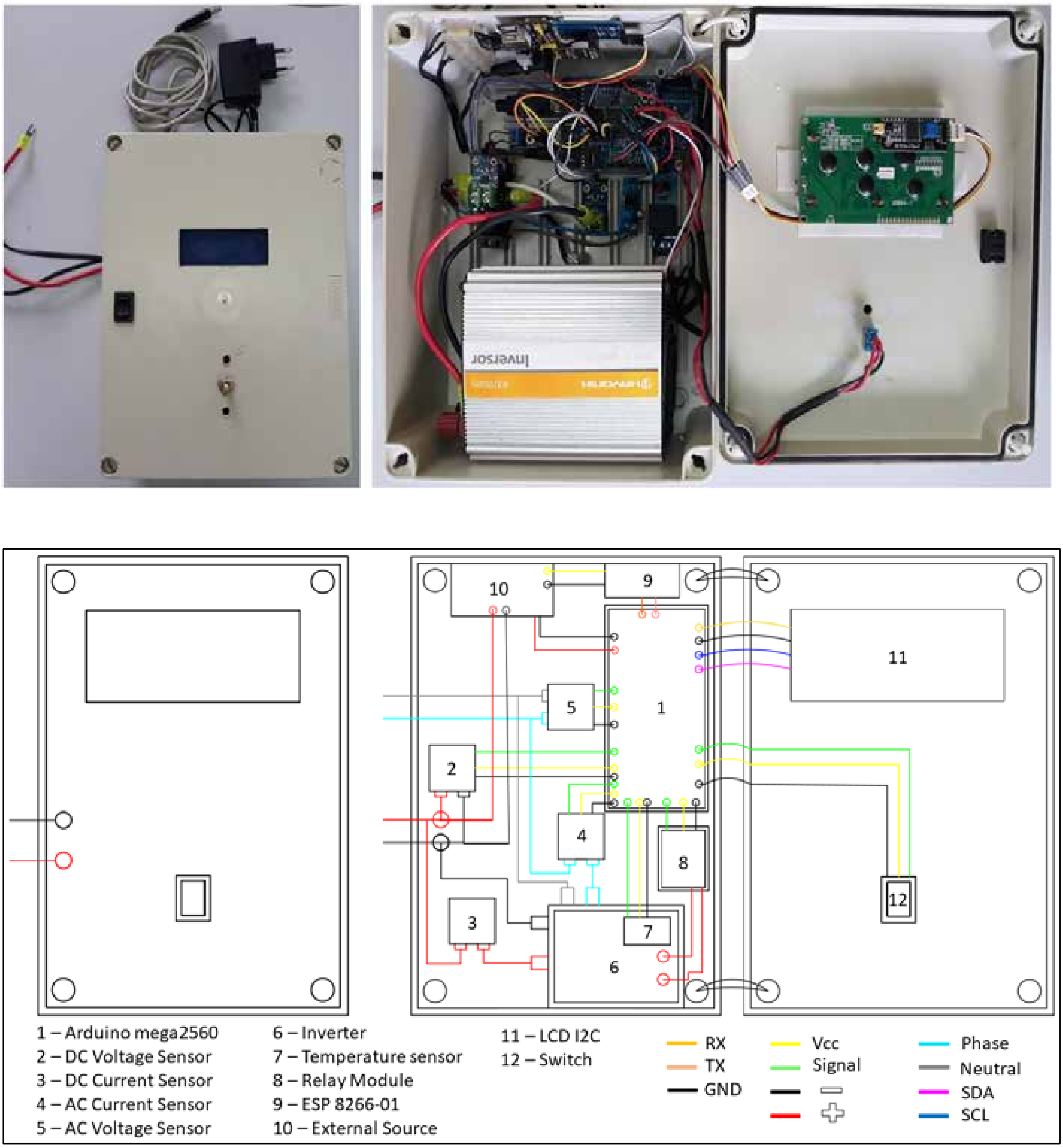

Figure 2. IoT acquisition and control platform.

2.2.2 Data Acquisition and Processing by IoT

The programming of the microcontroller was made from the Arduino IDE that is based on the computational language C. The reference voltage is 5V, and the relation between the ADC value and reference voltage in the analog terminal is given by Eq. (1).

$$V_{Read} = ADC\ x\ \frac{V_{Ref}}{2^n} \quad (1)$$

Consider: V_{Read} – Analog voltage input; V_{Ref} – Arduino reference voltage; n – Number of bits.

Relating the variable to be analyzed, the input voltage at the analog port allows the processing of data from analog sensors, considering that the output voltage of the sensor is usually linear. So, due to the analog sensor, the programming code of the DC voltage sensor takes into consideration Eq. (1).

However, it is necessary to multiply the result obtained by five, to calculate the actual voltage that was measured, because this sensor reduces 5 times the measured voltage when sending the data to the Arduino. Then, when it is measured 25V the sensor returns just 5V to the Arduino, to protect the port that does not support voltages greater than 5V.

The data processing of the DC current sensor is also related to Eq. (4) but, to obtain the proper current in the sensor is necessary to divide VRead by 66 mV. However, when measuring the AC current generated by the inverter circuit, it is necessary to carry out measurements with a sampling time of 166.86

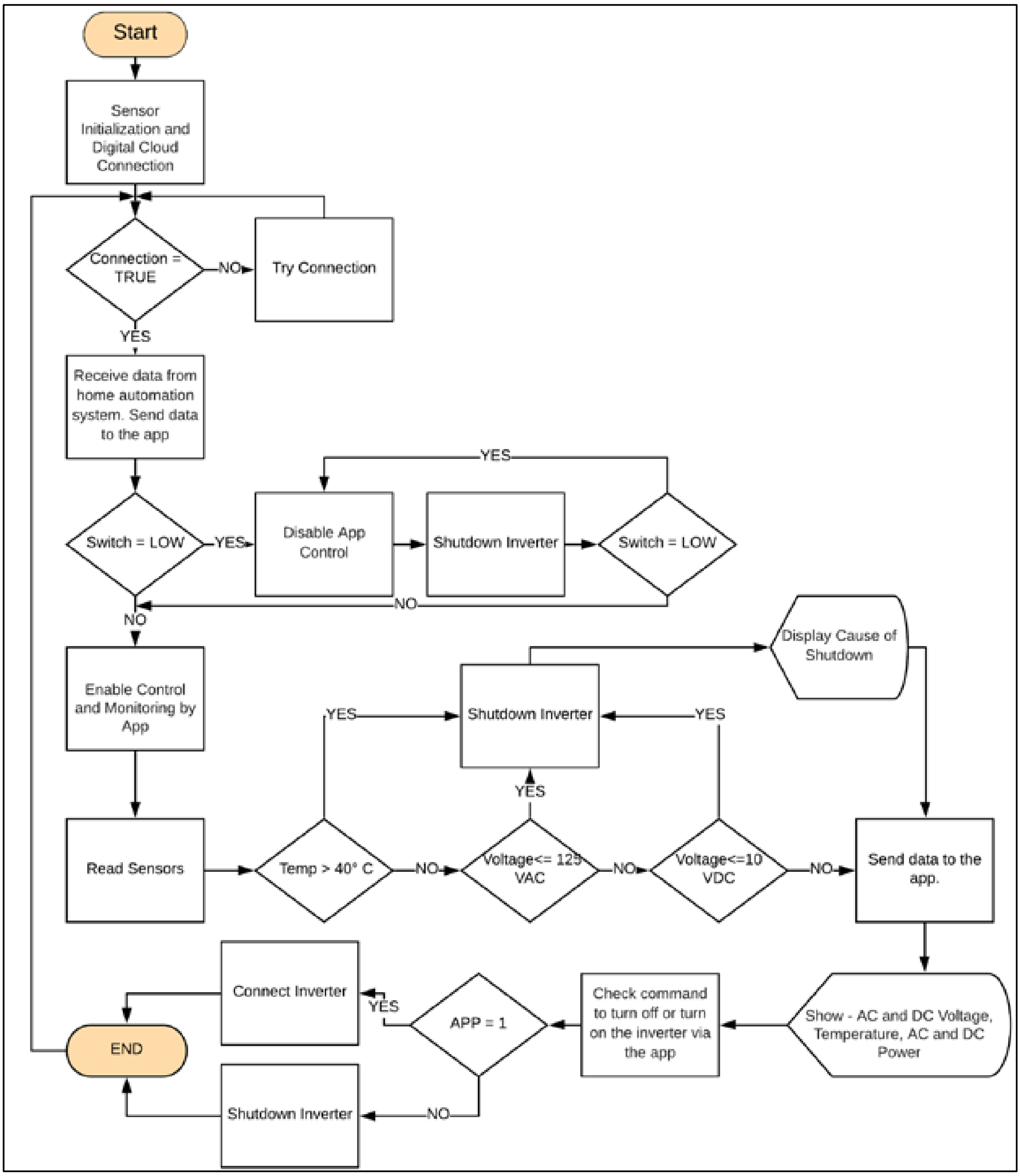

Figure 3. Flowchart of the developed program.

3. Results and Discussion

These results are related to photovoltaic modules integrated to a domotic system. It was based on values obtained by the temperature sensor and air humidity for fire alarm and access control. Thus, the monitoring system operates with minimum voltage values up to 11 V, and a battery of 8Ah was used, resulting in autonomy for approximately 29 hours.

3.1. Monitoring System Performance

The main variables during the operation of a photovoltaic generator are voltage and current, the measurement of these variables correctly is a critical point in a monitoring system of electrical quantities, thus generating reliability of the data presented by the sensors. Thus, a true RMS multimeter (Fluke) was used as a reference device, since this device has certified quality. With this, the performance of the DC/AC voltage and current sensors was evaluated.

Firstly, the DC voltage sensor and the multimeter were connected in parallel with the positive and negative terminals of the inverter input, in order for the two devices to measure voltages at the same point. The AC voltage was measured with the measurement point located in parallel with the phase and neutral terminals of the inverter. For DC measurements, Fluke was placed in series with the DC current sensor, using the negative terminal of the inverter's power input, repeating the AC measurement method. However, the measuring point is located on the neutral conductor of the inverter output. To perform the tests, it was necessary to supply DC power to the inverter at 12 V nominal. Thus, a load with a nominal power of 12 W to 127 V was connected to the AC terminals, and measurements were made. This load was not dimensioned by the calculations of the electrical characteristics of the system, therefore changing the battery autonomy. Table 1 shows the processed data.

Table 1 - Data analysis of multimeter and DC voltage sensor measurements.

The DC variable sensors, in general, showed satisfactory results about the cost, presenting low standard deviation and small variations concerning the Fluke average in the voltmeter function. The average variations of the DC voltage sensor with the DC voltmeter result in approximately 1,6688% less, the resistors that perform the voltage division of this sensor each have 1% accuracy. Another fact that can explain the variation is the capacity of the voltmeter's full-scale selection, thus increasing accuracy. This method of analysis was also used in the research by [14], because where they obtained results similar to the application carried out in this project. Figure 4 shows the data presented.

The DC variation to the ammeter was approximately 0.40% more when the two averages are compared. However, as much as this sensor has a low standard deviation in its measurements, considering the desired application, it presented a current peak of 0.02 A, higher than the ammeter and minimum currents with the same intensity. The difference between the delay measurements is related to the ammeter reading the instantaneous power since the sensor needs to do the processing with the Arduino that has a response time.

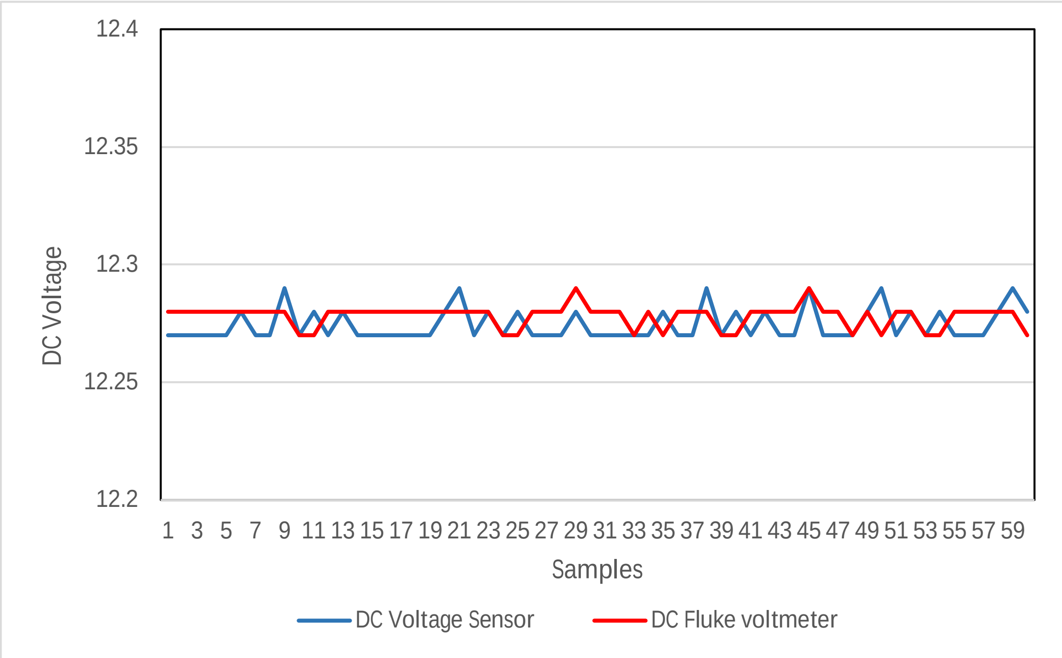

Figure 4. Voltage graphs between sensor and voltmeter.

For signal correction, it is observed in Table 1 that the DC averages present close values, showing an effective measure in adjusting the values obtained by the sensor to values that can represent a measurement made with the ammeter. Figure 5 shows the graph between data from the DC sensor and the DC ammeter.

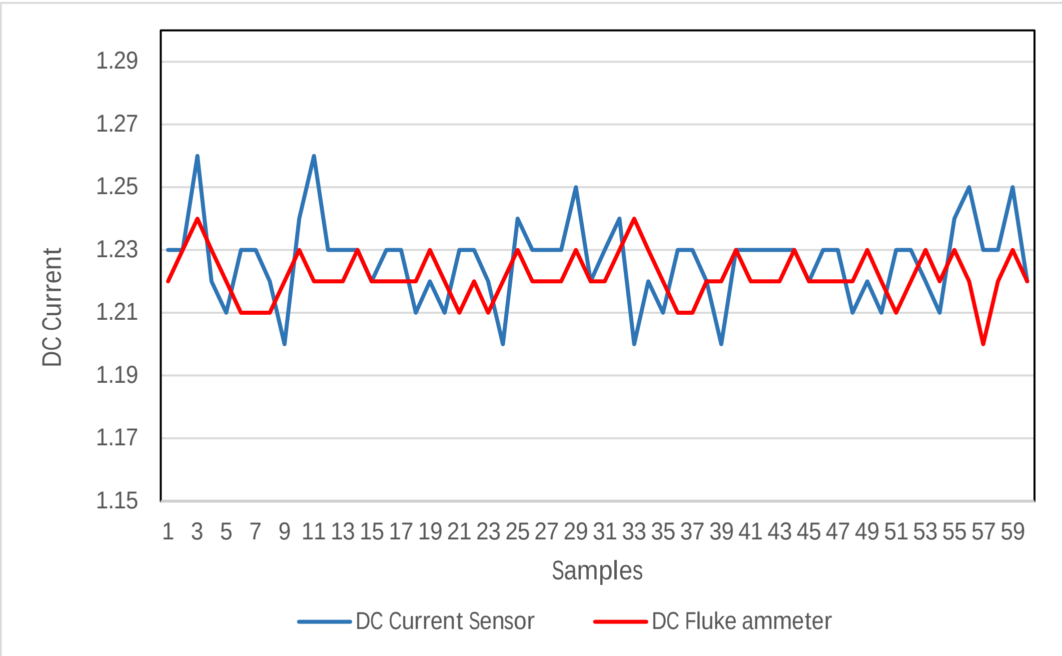

Figure 5. DC graphics.

The measurements of the AC variables were performed by processing the ADC values of the sensors. Then, the processed data is temporarily stored in two vectors with 600 positions each, such that these vectors are filled with AC voltage and current data. An algorithm tracks the maximum and minimum values of voltage and current, that is, peak to peak values within the vectors.

The maximum values are extracted separately and divided by $\sqrt{2}$, to obtain the RMS values, since the sensors measure alternating voltages and currents in a sinusoidal signal. However, the inverter used operates with an output signal adjusted to modified sine wave characteristics, these characteristics generate harmonic distortions in the signal and which, in turn, can present several variations in the signal measurement. Figure 6 shows the inverter signal measured on an oscilloscope with a frequency range from 45Hz to 440Hz.

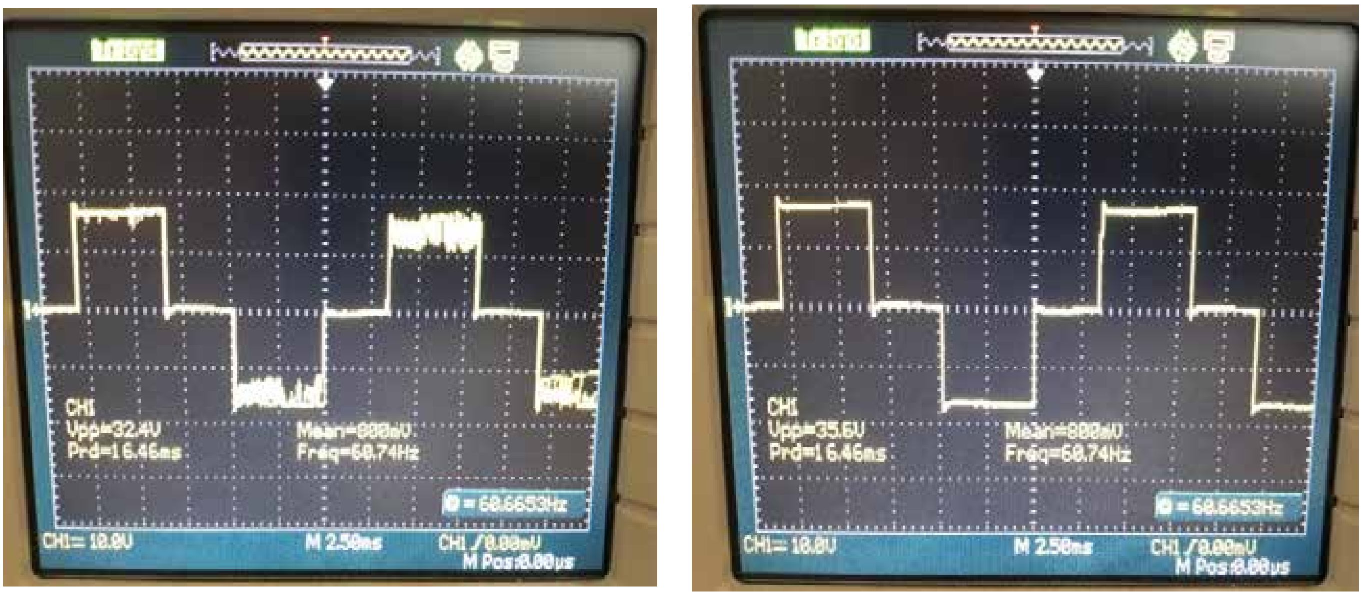

Figure 6. Oscilloscope output signal.

The data presented by the voltage and current sensors showed considerable variations with the multimeter (Table 1). These variations can be explained by the harmonic distortions, due to the sensor monitoring the evolution of voltages and currents and the multimeter measuring the instantaneous power in the signal, not necessarily measuring at the same time of the sensor. Figure 7 shows the signal with the effect of harmonic distortions, and lower Vpp voltages (peak-to-peak voltage) are observed when compared to the signal that does not intensely present such distortions. However, this type of deformation is usually generated by devices that have a non-linear relationship between voltage and current, such as transformers and motors, subject to saturation of their ferromagnetic core. Another explanation is due to the magnetic saturation of transformers, which can, for instance, be produced by the fast switching of electronic power converters.

The ideal solution for reducing harmonic distortions in current signals in electrical systems is the use of tuned filters connected in derivation at the source, functioning as a current divider [15]. However, when analyzing the correlation between voltages and currents measured by the AC sensors and the Fluke in the AC voltmeter and AC ammeter configuration. Through the use of the simple linear regression model taking into account the power observed by the two measuring devices is obtained that there is a 71.57% relationship between the measurements of the AC sensors representing a probable power value measured by the multimeter. Figure 7 shows the result of the simple regression as well as the linear model adjustment equation.

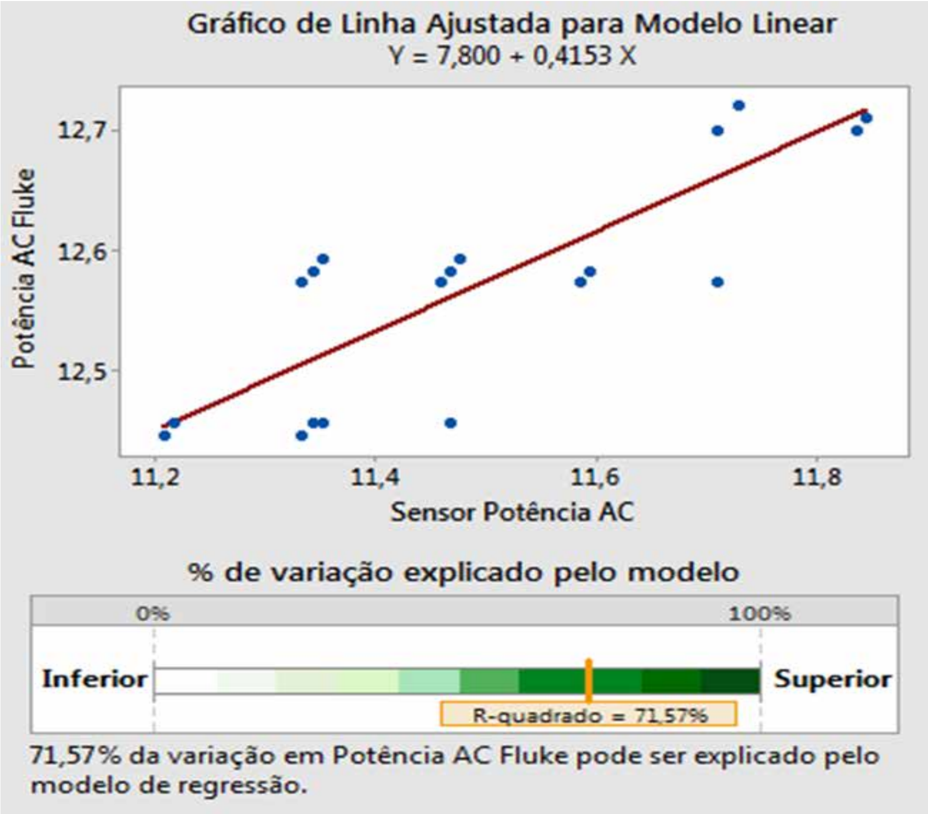

Figure 7. Line graph adjusted for the linear model.

3.2. Photovoltaic Generation

The 12W load coupled to the inverter output was disconnected, and from the measurements of the sensors, the photovoltaic generator was subjected to operation tests. Initially, the evolution of battery and photovoltaic module voltages connected to the charge controller was analyzed. For such analysis, it was necessary to connect the DC voltage sensor to the battery terminals next to the charge controller and Fluke to the photovoltaic module terminals. Figure 8 shows the evolution of battery and photovoltaic module voltages over 12 hours, taking measurements every 5 minutes.

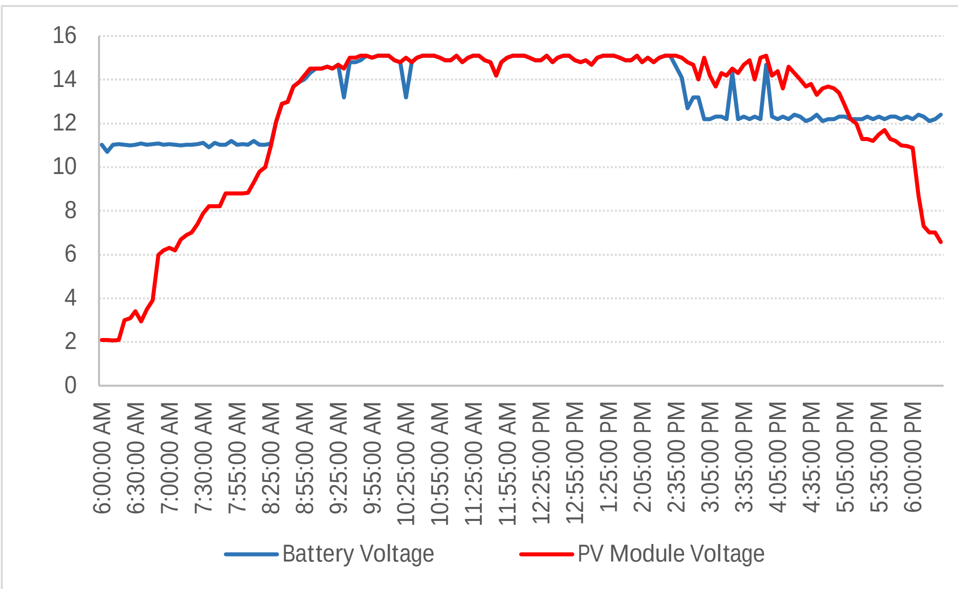

Figure 8. Evolution of battery and photovoltaic module voltages throughout the day.

The battery has entered a state of fluctuation (maximum voltage), which is when the source (PV module) is supplying the consumption and the maximum charge level of the battery. In the graph in Figure 8, it is seen that when the panel voltage drops, shortly after that, the battery voltage also drops, as it started to discharge (it left the float). Between 14:35 and 15:05, it is observed that the battery left the float, which is because the photovoltaic module is no longer providing the necessary power. Thus, the battery starts to discharge because it is feeding the load with less intensity. Subsequently, the photovoltaic module was disconnected from the system in order to obtain battery autonomy with the monitoring and control equipment operating uninterruptedly, fed only with the power supplied by the battery. Figure 9 shows the battery discharge.

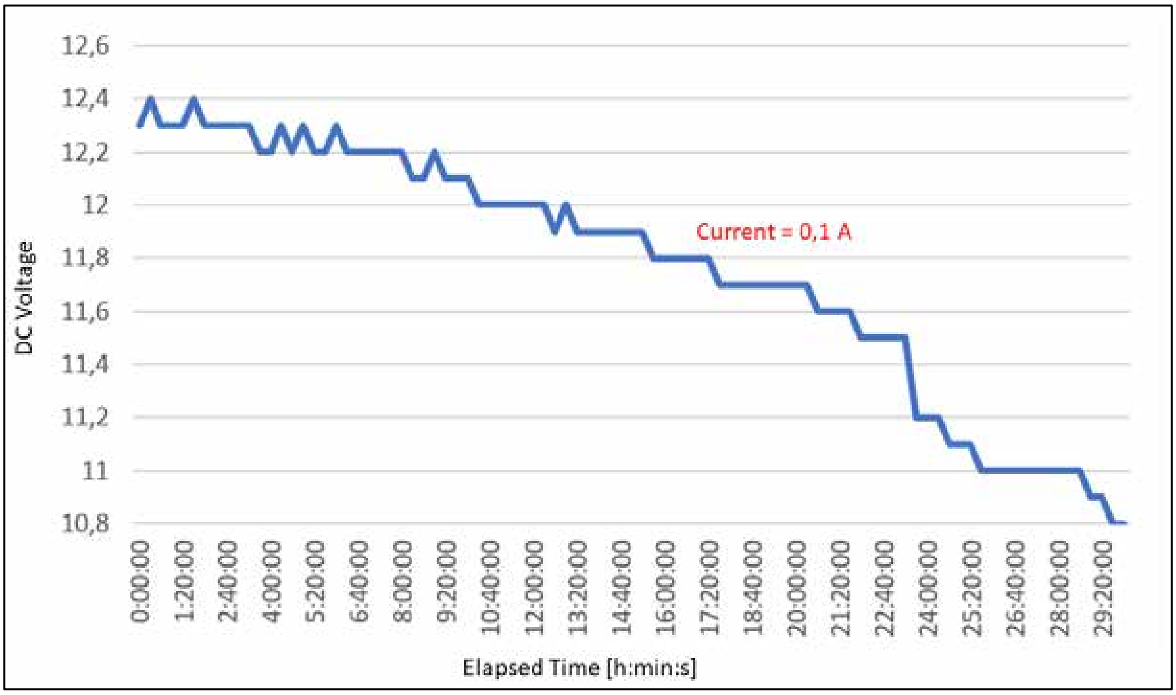

Figure 9. Battery discharge graph.

The monitoring system operates with minimum voltage values up to 11V, and it is noted that the battery can supply the load in up to 29 hours. The dimensioning of the battery predicted that it would supply the demand in up to 1.5 days. However, an 8 Ah battery was used, when the ideal would be 8.91 Ah, resulting in the autonomy of 29 hours, still showing a result satisfactory.

3.3. Domotic System Prototype

For detection and warning in fire situations, an initial step was necessary to calibrate the sensor. The calibration is the fundamental basis for the correct functioning of the device to measure the sensor output voltage on the analog pin and to the detection of the flame sources. The system converts the ADC value into a voltage signal, and from then, it can begin to analyze. In the fire simulation, 150g of cotton moistened with 15ml of ethyl alcohol was used in 70%, located approximately 2 meters away from the infrared receptor of the flame sensor. This analog sensor can detect flames when the wavelength is between 760 nm to 1100 nm. A potentiometer can alter the sensitivity adjustment of the sensor according to the need.

In the experiments, this sensor obtained a more expressive performance when the focus of the flames of fire was more approximate, presenting values of lower voltages compared to the data.

In this way, the alert system has been configured to send an alert via app and trigger buzzer when the sensor has ADC value below 800 nm, resulting in a voltage of approximately 3.90 V. It is important to emphasize that the fire warning system just becomes in the operation when activated via the app. Another function of this domotic system is the measurement of temperature and relative air humidity; these data are vital for the comfort of living beings. The DHT22 sensor has been used and presenting data consistent with the measurement. Figure 10 shows an image of the developed domotic hardware.

Figure 10. Hardware Prototype.

3.4. IoT Platform

The communication system on the Blynk digital cloud platform is carried out via Wi-Fi with the ESP8266-01 module. This module is connected to a router with internet access, and the data transmission occurs through port 8433 (SSL). The digital cloud used in connection and authentication of the Arduino Mega with the online platform is about 37s on a stable Internet connection and an average speed of 15 Mb/s. Considering the time of sending and receiving data (latency) in average 13ms.

The app can be used simultaneously on multiple devices, requiring an administrator user. So, the user has a 32-character access key sent to the email when the application has been created. In this version of the app (administrator), it is possible to add or remove the requirement for monitoring and control systems, as well as to make changes to the app in case of maintenance, and the changes occur synchronously between the connected devices.

To this application, the platform has three screens to analyze the monitored variables. The first screen contains side-by-side information of the photovoltaic system off-grid DC and AC. The second screen contains the monitored electric data graphs with a capacity to store values about one year of operation, and the data stored in charts can be exported to other platforms. The third and last screen contains the variables monitored in the home automation system; besides this, an on/off control buttons on the inverter and fire alarm system. Figure 5 shows the visualization screens of the monitoring system in the Blynk IoT design.

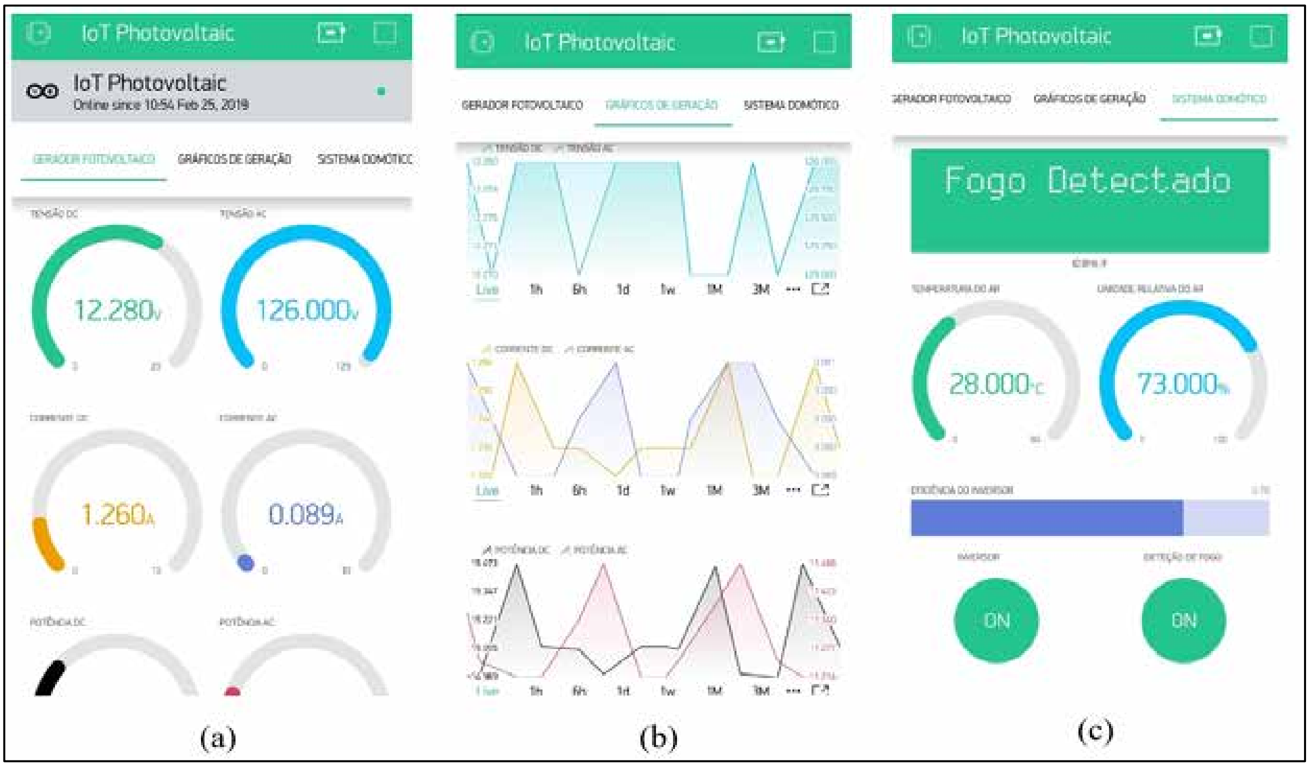

Figure 5. IoT information of the photovoltaic system.

4. Conclusion

The objective of this project was to develop a PV controlled system for home automation by IoT. The results showed the operation of a photovoltaic generator, with the use of DC/AC voltage sensors and

DC/AC for performance analysis, to alert against fires and control the access in the residence where the system is installed. It was verified the necessity of a study in more detail regarding devices of lower power consumption, to improve the efficiency in the energy autonomy of the proposed system. The results obtained presented feasibility of the implementation of this work, due to the operation of the system present excellent efficiency, and because it is a low cost, compared to proprietary systems. The differentials presented in this work are related to the possibility of altering the hardware and software, if necessary and inserting additional sensors in both the photovoltaic generator and the home automation system. Besides, it allows the easy replacement in the exchange of spare parts, integration of data with the home automation, and the photovoltaic system in a single platform, not requiring additional applications for its monitoring and control.

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